THE 1.0-4.5 GHz ZEBRAS IN THE JUNE 6, 2000 FLARE

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ABSTRACT

A long lasting X2.3 flare was recorded in radio waves during 15:00-17:00 UT on June 6, 2000. A full-halo coronal mass ejection was associated with this flare. The flare was unusually rich in the high-frequency radio zebras above 1 GHz. A unique case of zebra branches in a harmonic ratio of 1:2 was observed. These zebras were analyzed and interpreted in the model based on the double plasma resonance instability. Longitudinal upper-hybrid waves are excited at positions of cyclotron resonances and then transformed into electromagnetic waves. Using this model, the magnetic field strength in this flare is estimated.

INTRODUCTION

The metric radio zebras have been known for a long time (Slottje 1971). Recently, zebras have been also reported in the frequency range of 1.0-4.5 GHz. All these zebras patterns can be used for magnetic field estimates in the corona. Recently, a new model for zebra emissions was suggested by Ledenev *et al.* (2001), which gives more realistic values of the magnetic fields in the lower heights of the solar flare atmosphere. In the present paper, we apply this model of zebras to the case of the June 6, 2000 flare, which was very rich in high-frequency zebra patterns. Here, we described briefly the observations and the magnetic field estimates.

OBSERVATIONS

The June 6, 2000 flare, classified as X2.3, was observed during 15:00-17:00 UT in the active region NOAA AR 9026. This flare was unusually rich in the high-frequency zebras. Several examples were recorded in the 1.2-1.7 GHz and 2.0-4.5 GHz frequency ranges, respectively, by the Brazilian Solar Spectroscope (BSS) (Sawant *et al.* 2001) and by the Ondřejov Observatory and four of them are shown in the Table 1. The frequency ratios of the neighboring zebra lines are below the value of 1.024 and there is a tendency to decrease these ratios towards lower frequencies. The number of observed zebra lines is in the range of 2-6 lines. In one case unique zebra patterns in a harmonic ratio of 1:2 were observed. While in the low-frequency band 3 zebra lines were recognized, on the double frequency only 2 zebra lines were recorded.

MAGNETIC FIELD ESTIMATES

In agreement with the model of Ledenev *et al.* (2001) we assume that the zebra pattern lines are generated at positions in the solar atmosphere where the following resonance condition is fulfilled: $\omega_{UH} = (\omega_{pe}^2 + \omega_{Be}^2)^{1/2} = s\,\omega_{Be}$, where ω_{UH}, ω_{pe}, and ω_{Be} are the upper hybrid, electron plasma and cyclotron frequencies, respectively and s is the integer harmonic number. The characteristic space scale of the electron density is assumed to

Table 1. Zebra patterns in the 1.0-4.5 GHz range.

#	Start (UT)	End (UT)	Frequency Range (MHz)	No. Zebra	Zebra line frequency	Ratio of succeeding frequencies	Magnetic field (G)
1	15:37:42	15:37:50	1590-1685	3	1620/1635/1675	1.009/1.024	150
2	15:42:51	15:42:52	1220-1265	3	1220/1240/1265	1.016/1.020	113
1	15:37:44	15:37:49	3300-3400	2	3290/3355	1.019	150
2	15:43:12	15:43:13	3500-4000	6	3639/3683/3761	1.015/1.018/1.015	178
					3818/3897/3977	1.020/1.020	

be much greater than that of the magnetic field. Then, the ratio of the neighboring zebra line frequencies is:

$$\omega_s/\omega_{s+1} = [\omega_{pes}/\omega_{pes+1}]\left[s^3(s+2)/(s+1)^3(s-1)\right]^{1/2}. \tag{1}$$

If we take roughly $\omega_{pes} \approx \omega_{pes+1}$ then $\omega_2/\omega_3 \approx 1.088$, $\omega_3/\omega_4 \approx 1.027$, $\omega_4/\omega_5 \approx 1.012$, $\omega_5/\omega_6 \approx 1.006$ and so on.

For magnetic field estimation the most important aspect is the determination of the s parameter for the zebra line with the highest frequency. This can be done by a comparison of the highest frequency ratio in the specific zebra pattern with the theoretical minimum values. In our case, the fourth harmonic ($s = 4$) is the most probable. Excepting the zebra patterns in harmonic ratio (1:2) we assume that the zebras are observed on the frequency of the upper hybrid waves (fundamental branch). Then the magnetic field strength from different zebra patterns can be determined as $B = f_{max}/(2.8s)$, where $s = 4$ in our case, B is in Gauss and f_{max} is the highest frequency of zebra lines in MHz. Thus we estimate the magnetic field to be in the range of 110-180 G.

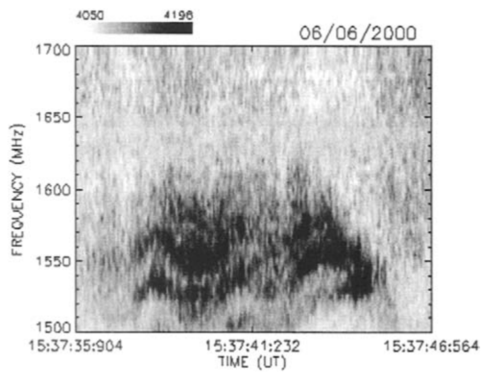

Fig. 1. *Dynamic spectrum of zebra recorded by the BSS, simultaneously with Ondřejov Observatory.*

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